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Ultrasound estimation of volume of postoperative pleural effusion in cardiac surgery patients

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Abstract

The aim of this study was to establish a practical simplified formula to facilitate the management of a frequently occurring postoperative complication, pleural effusion. Chest ultrasonography with better sensitivity and reliability in the diagnosis of pleural effusions than chest X-ray can be repeated serially at the bedside without any radiation risk. One hundred and fifty patients after cardiac surgery with basal pleural opacity on chest X-ray have been included in our prospective observational study during a two-year period. Effusion was confirmed on postoperative day (POD) 5.9 ± 3.2 per chest ultrasound sonography. Inclusion criteria for subsequent thoracentesis based on clinical grounds alone and were not protocol-driven. Major inclusion criteria were: dyspnea and peripheral oxygen saturation (SpO_2) levels $\leq 92\%$ and the maximal distance between mid-height of the diaphragm and visceral pleura ($D \geq 30$ mm). One hundred and thirty-five patients (90%) were drained with a 14-G needle if according to the simplified formula: $V \text{ (ml)} = [16 \times D \text{ (mm)}]$ the volume of the pleural effusion was around 500 ml. The success rate of obtaining fluid was 100% without any complications. There is a high accuracy between the estimated and drained pleural effusion. Simple quantification of pleural effusion enables time and cost-effective decision-making for thoracentesis in postoperative patients.
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Keywords: Cardiac surgery; Pleural effusion; Thoracentesis; Ultrasound

1. Introduction

In postoperative patients after cardiac surgery, large amounts of pleural effusion may affect the recovery period requiring a longer hospital stay due to dyspnea. On the other hand, adverse effects of large pleural effusion, including delayed lung expansion, atelectasis, risk of pneumonia, possible association with arrhythmias (e.g. atrial fibrillation), and small risk of developing into empyema are illustrated just to emphasize the clinical relevance. Early diagnosis and quantification of pleural effusion warrants an ideal postoperative course with adequate treatment.

Chest sonography shows better sensitivity and reliability or diagnosis of pleural effusions than chest X-ray [1, 2]. Chest sonography can be repeated serially at the bedside without any radiation risk. Thoracentesis performed under ultrasound showed a reduced rate of complications [2–4]. When chest X-rays suggest effusion that is not confirmed by ultrasound, unnecessary thoracentesis can be avoided. Suspected fluid volume is an important factor when considering pleural drainage. In the case of a small amount of pleural fluid, the benefit of puncture should be weighed against the risk of complications, such as pneumothorax or bleeding, particularly in patients already treated with oral anticoagulants or thrombopenic patients [5]. In the literature, there are few published studies regarding pleural effusion treatment in spontaneously breathing patients post-cardiac surgery. Therefore, a simple method to quantify the volume of effusion may be helpful in the decision-making process for treatment options.

2. Materials and methods

The study included patients with primary indication for thoracentesis and was approved by the Hospital Ethics Committee. The data on 135 (90%) consecutive thoracenteses performed under ultrasound guidance in spontaneously breathing patients after cardiac surgery (90 males and 45 females), were prospectively collected between 2007 and 2009. Eighty-two patients (61%) had received an aortic valve replacement (70% biological prosthesis) and 53 (39%) patients had undergone a coronary artery bypass graft (CABG). Patients were routinely examined by chest X-ray on postoperative day (POD) 1, 3, 5 and 7 and, in the case of valve replacement, on POD 5 by echocardiography. These patients showed blunting of the lateral costophrenic angle associated with an opacification on chest X-ray, suggesting pleural effusion which was later confirmed in all by ultrasonography (Fig. 1). Effusion was confirmed on POD 5.9 ± 3.2 using pre-puncture ultrasound. Patients on

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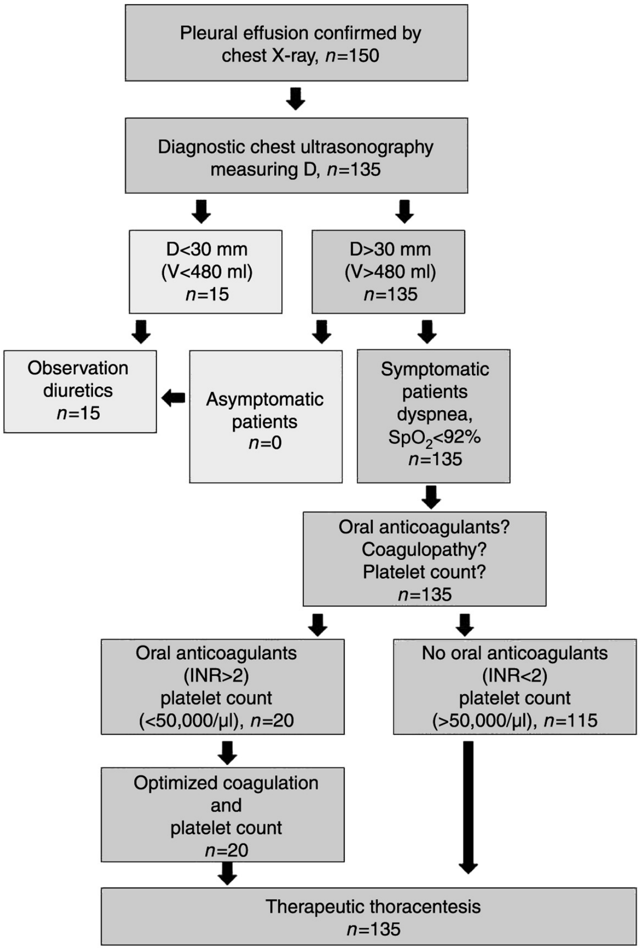

Fig. 1. Flow chart diagram to depict inclusion criteria of patients, clinical decision-making and management of postoperative pleural effusions.

oral anticoagulants (usually on POD 5) or coagulopathy [prothrombin time >2.0 by international normalised ratio (INR)] and/or platelet count $<50\times10^9$/l were also included into the study (20 patients) but they were not drained immediately after ultrasonographic evaluation of the pleural effusion, but, if clinically tolerable, 12 h later after correction of the INR value (target value <2.0) by application of vitamin K derivatives or in the case of low platelet count after substitution of thrombocytes to reach a value $>50\times10^9$/l. To eliminate the effects of possible deformations of pleural space, the authors excluded patients with thoracic deformities, post-lung surgery or diaphragm pathology. The decision to perform thoracentesis was made on clinical grounds alone and was not protocol-driven; major clinical criteria were: dyspnea and peripheral oxygen saturation (SpO_2) levels ≤92% obtained without supplemental oxygen.

For ultrasound examination patients were in a sitting position. The ultrasound probe (S5–1, 2.5 MHz, iE33 Philips, Philips, Germany) was moved in a cranial direction in the mid-scapular line. The visceral layer moved during each respiratory cycle with a decrease in interpleural separation during inspiration. The lung behind the pleural effusion appeared either ventilated or consolidated. The maximal distance between mid-height of the diaphragm and visceral pleura (D) was measured after freezing the image in end-expiration (Fig. 2). The diaphragm, liver and spleen had to be clearly visualised before tapping to avoid accidental puncture. An interpleural distance D≥30 mm was required to include the patient into the study (Fig. 1). Thoracentesis was performed in the mid-scapular line after previous determination with the probe. All thoracenteses were therapeutic, i.e. aimed at draining the pleural space to a large extent, but to the determined maximum of 2000 ml just to prevent pulmonary oedema. We performed the thoracentesis with a syringe pump system mounted onto the 14 G catheter-over-needle enabling aspiration of the pleural effusion. The volume of fluid (V) was recorded and the tap was terminated when no more fluid could be aspirated. All patients with incomplete aspiration of pleural fluid who had separation of pleural layers of 20 mm on post-puncture ultrasound were excluded from the study. A chest X-ray was performed in all patients after thoracentesis.

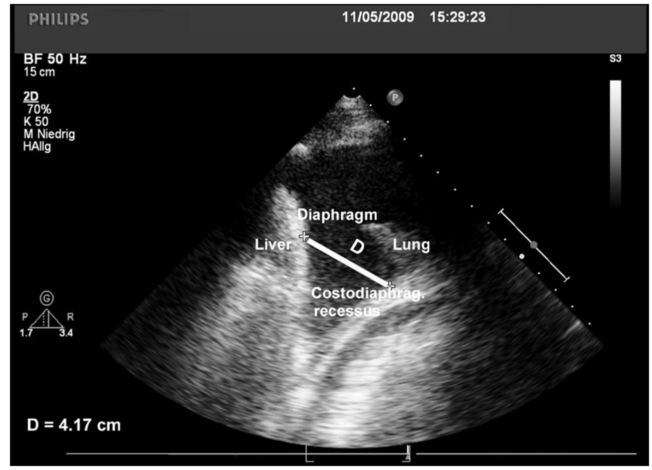

Fig. 2. Longitudinal ultrasonographic view showing a large effusion delimited by the costodiaphragmatic recessus, diaphragm, parietal and visceral pleura surrounding consolidated lung. In this patient, $D_{pre}=4.17$ cm. With the simplified formula V_{pre} (ml) = [16×D] the effusion was estimated 834 ml, with the derived formula V_{pre} (ml) = [15.06×D]+21.45 an amount of 641.47 ml was calculated. In the following thoracentesis 750 ml serous effusion was drained.

Statistical analysis was performed using Graph Pad Prism, version 5.0. The data distribution was checked using Bartlett's test for equal variances showing normal distribution ($P<0.01$ for pleural volume and distance). Results are expressed as mean±standard deviation (S.D). Correlation between volume of pleural fluid and D was examined by linear regression (Pearson product moment correlation). The mean prediction error was calculated as the mean of the differences between the predicted and drained effusion volumes and the standard error of the estimate (SEE) was calculated additionally. Presence of complications was recorded. The data from left and right pleural effusions were compared using analysis of covariance.

3. Results

A total of 150 patients with pleural effusions were evaluated. Fifteen out of 150 patients included into this study

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were excluded from thoracentesis because of $D<30$ mm, i.e. not fulfilling the inclusion criteria for thoracentesis. A total of 135 (90 males and 45 females) spontaneously breathing patients were drained successfully under ultrasound guidance if the criteria $D\geq30$ mm and estimated volume of the pleural effusion around 500 ml were fulfilled. One tapping under ultrasound guidance was enough in all cases and there was no need for repetitive tapping. Median patient age was 60 (range 45–67) years with a mean body-mass-index of 28.17 ± 2.89 (range 23.44–36.73) kg/m^2.

Mean distance between mid-height of the diaphragm and visceral pleura in end-expiration (D_{pre}) was 45.5 ± 12.7 mm. Mean drained volume $V_{drained}$ was 706.1 ± 214 ml (range 200–1250 ml). From the drained volume of pleural fluid implementing D_{pre} following formula was derived: $V_{drained}$ (ml)$=(15.06\times D_{pre})+21.45$. According to this formula the predicted V was 705.9 ± 190.7 ml (range 458.2–1452 ml). Significant positive correlation between both D_{pre} and $V_{drained}$ was found: $r=0.89$; $r^2=0.7941$; $P<0.001$ (Fig. 3).

For practical purposes the amount of pleural fluid can be estimated with the simplified formula: V_{pre} (ml)$=16\times D_{pre}$. Mean calculated V_{pre} with the simplified formula was 727.2 ± 202.6 ml (range 464–1520).

Standard error of estimate using the derived formula was 97.42 ml. Mean prediction error of V_{pre} using the derived formula was -0.18 ± 97.06 ml and -21.1 ± 97.78 using the simplified formula.

After thoracentesis the residual pleural effusion was calculated by ultrasonographic measurement of $D_{post}=9.14\pm5.77$ mm. Implementing D_{post} into the derived formula (V_{post} (ml)$=(15.06\times D_{post})+21.45$) resulted in $V_{post}=159.1\pm108.35$ ml. Implementing D_{post} into the simplified formula [V_{pre} (ml)$=16\times D_{pre}$] resulted in $V_{post}=146.24\pm92.32$ ml.

Success rate of obtaining fluid under ultrasound guidance was 100%; the incidence of pneumothorax or bleeding was zero. Seventy-one percent of pleural effusions drained was hemorrhagic-serous and the rest purely serous. Mean peripheral SpO_2 before and after thoracentesis were $90.73\%\pm1.27$ and 98.39 ± 1.97. After thoracentesis, respiration improved and the patients could be discharged on POD 9–10, otherwise patients had to stay 3 ± 1.5 (range 1–5) days longer in the hospital if only treated with diuretics in an observational fashion.

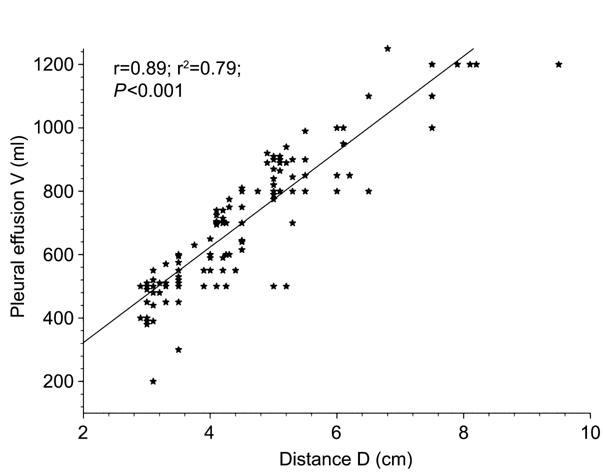

Fig. 3. Correlation between measured distance D and 135 thoracenteses; each marked with a star representing drained volume. The volume had been estimated with the simplified formula V_{pre} (ml)$=[16\times D]$. From the regression following formula V_{pre} (ml)$=[15.06\times D]+21.45$ was derived. The correlation coefficient is $r=0.89$; $r^2=0.7941$; $P<0.001$.

4. Discussion

In the presented study our goal was to establish a practical algorithm by formulating a simplified calculation to facilitate the management of a frequently occurring postoperative complication, pleural effusion. It is generally accepted that chest ultrasonography shows better sensitivity and reliability in the diagnosis of pleural effusions than chest X-ray [1, 2]. Chest ultrasonography can be repeated serially at the bedside without any radiation risk. Modern miniaturized advanced ultrasound systems are portable, allowing physicians to quickly perform rapid diagnostics and thoracentesis right at a patient's bedside, ideal for emergency situations. The advantage of ultrasound evaluation of pleural effusion is obvious [3, 6, 7]: it helps to quantify the pleural fluid volume using our simplified formula V (ml)$=[16\times D$ (mm)] and hence helps in deciding whether or not thoracentesis should be performed. The complication rate in this study was zero, specifically no pneumothorax was noted. The major advantage of thoracentesis per tapping with a 14-G needle is in its minimal invasiveness without a need of skin incision, as being required by a formal chest tube or Seldinger Chest Drainage Kit Portex™ type. On the other hand, patients are not immobilized after thoracentesis with the method presented in this study. The authors excluded small pleural collections by excluding patients with pleural separation <30 mm on initial ultrasound examination. It was also suggested that the relationship may not be as linear and clinically important for pleural separations below 20 mm [8–10]. One potential source of error for volume underestimation was lower lobe atelectasis with large effusions over 1000 ml, which may lead to different volume 'morphology' not amenable to quantification [2]. Sonographic measurement is also influenced by the size of thoracic cavity. In large thoraces in tall people, the layer measured by ultrasound may cause underestimation of the actual volume of pleural fluid. The results could also be influenced by the examination technique: the transducer must not be angled or tilted, which may result in a scan that is oblique to the transverse plane. Such measurement may produce overestimation of the effusion width. Finally, few limitations of this study should be mentioned. The small number of the patients could be one of them but on the other side the derived formula is highly accurate, justifying the chosen patient collective. Of course a high intra- and interobserver variability of the performed ultrasonographic measurement may exist accentuating the need for some expertise in ultrasonography.

5. Conclusion

For bedside decisions practical algorithms, like our presented management of postoperative pleural effusions are beneficial. With our simplified formula we could easily quantify pleural effusion and could decide cost and time effectively whether or not to perform a thoracentesis. Thoracentesis of pleural effusions ≥500 ml in patients

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following cardiac surgery under ultrasound guidance proved to be a safe procedure, and improved postoperative respiration and recovery, and shortened the postoperative stay.

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